STRINGS MICHIGAN THEORY

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Millennium Madness

The Top Ten Questions in Fundamental Physics

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OPENING QUESTIONS

David Gross

It is quite appropriate to open this workshop on string theory with a list of questions. In the flurry of excitement generated by recent developments some people have wondered whether we might be witnessing the beginning of the end of physics. For the first time we have a theory which appears, in principle, to be capable of answering all the traditional questions of elementary particle physics. Preliminary investigation of the phenomenology of the $E_8 \times E_8$ heterotic string is quite encouraging. However the game is far from being over, quite the opposite is the case. There are there many unsolved problems and deep mysteries that need to be understood before one can claim success. In addition we have only begun to explore the structure of these new theories. It is not at all clear where these explorations will lead us. If history is a reliable guide to the future then, as our understanding of the theory improves, new domains of physics and new questions will appear. I therefore present below, in the belief that questions are often more important than answers, a list of open questions. Most of these are well known to any worker in this field, are serving as a guide to current research and are addressed in the contributions to this workshop.

1. What is String Theory?

This is a strange question since we clearly know what string theory is to the extent that we can construct the theory and calculate some of its properties. However our construction of the theory has proceeded in an *ad hoc* fashion, often producing, for apparently mysterious reasons, structures that appear miraculous. It is evident that we are far from fully understanding the deep symmetries and physical principles that must underlie these theories. It is hoped that the recent efforts to construct covariant second quantized string field theories will shed light on this crucial question.

✓✓ 2. How Many String Theories are There?

Do there exist more consistent string theories than the known five — the two forms of the closed superstring, the $SO(32)$ open superstring and the two forms of the heterotic string? Do there exist fewer, in the sense that some of the above might be different manifestations (different vacua?) of the same theory? Are some of the known theories actually inconsistent?

ANSWERED

✓ 3. String Technology

This is not a question but a program of development. Much work remains to be done in developing the calculational techniques of string theory, including control of multiloop perturbation theory and the construction of manifestly supersymmetric and covariant methods of calculation.

MUCH PROGRESS

4. What is the Nature of String Perturbation Theory?

Our present understanding of string theory has been restricted to perturbative treatments. Does this perturbation theory converge? Most likely it does not. In that case when does it give a reliable asympototic expansion of physical quantities? How can one go beyond perturbation theory and what is the nature of nonperturbative string dynamics? This question is particularly difficult since we currently lack a useful non-perturbative formulation of the theory. LARGELY ANSWERED

5. String Phenomenology

Here there are many questions that can all be summarized by asking whether one can construct a totally realistic four-dimensional model which is consistent with string theory and agrees with observation? NOT YET.

6. What Picks the Correct Vacuum?

This is one of the great mysteries of the theory which appears, at least when treated perturbatively, to possess an enormous number of acceptable (stable) vacuum states. Why, for example, don't we live in ten dimensions? Does the theory possess a unique vacuum, in which case all dimensionless physical parameters would be calculable or is the vacuum truly degenerate, in which case we would have free parameters? How does the value of the dilaton field get fixed, thereby giving the dilaton a mass? Does the vanishing of the cosmological constant survive the mechanism that lifts the vacuum degeneracy? LITTLE PROGRESS

7. What is the Nature of High Energy Physics?

By this I mean what does physics look like at energies well above the Planck mass scale? This is a question that is addressable, in principle, for the first time, and might be of more than academic interest for cosmology. In analogy with past theories one might expect physics in this domain to look entirely different. Does the string undergo a phase transition at high temperatures or densities to a new phase, as is perhaps indicated by the existence of a limiting temperature? Can one avoid in string theory the ubiquitous singularities that plague general relativity? SOME PROGRESS

8. Is There a Measurable, Qualitatively Distinctive Prediction of String Theory?

String theories can, in principle, make many "postdictions" (such as the calculation of the mass ratios of quarks and leptons, Higgs masses and couplings, gauge couplings, etc.). They can also make many new predictions (such as the masses of the supersymmetric partners of the observed particles, new gauge interactions, etc.). These would be sufficient to establish the validity of the theory, however in each case one can imagine (although with some difficulty) conventional field theories coming up with similar pre or post dictions. It would be nice to predict a phenomenon, which would be accessible at observable energies and is uniquely characteristic of string theory.

A LITTLE PROGRESS.

Excluded Questions

IMPORTANT, FUNDAMENTAL QUESTIONS IN OTHER FIELDS OF PHYSICS

(Condensed matter, Astrophysics, Biophysics, ...)

Personal Questions

e.g.

How does one get tenure?

(Finn Larsen)

Will Witten stay in California?

(Everyone)

Question 1

Are all the (measurable) dimensionless parameters that characterize the physical universe calculable in principle or are some merely determined by historical or quantum mechanical accident and uncalculable?

David Gross
Institute for Theoretical Physics,
University of California, Santa Barbara

Question 2

How can quantum gravity help explain the origin of the universe?

Edward Witten

California Institute of Technology and

Institute for Advanced Study, Princeton

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Question 3

What is the lifetime of the proton and how do we understand it?

Steve Gubser
Princeton University and
California Institute of Technology

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Question 4

Is Nature supersymmetric, and if so, how is supersymmetry broken?

Sergio Ferrara
CERN (European Laboratory of Particle Physics)
Gordon Kane
University of Michigan

Question 5

Why does the universe appear to have one time and three space dimensions?

Shamit Kachru
University of California, Berkeley
Sunil Mukhi
Tata Institute of Fundamental Research
Hiroshi Ooguri
California Institute of Technology

Question 6

Why does the cosmological constant have the value that it has, is it zero and is it really constant?

Andrew Chamblin
Massachusetts Institute of Technology
Renata Kallosh
Stanford University

Question 7

What are the fundamental degrees of freedom of M-theory (the theory whose low-energy limit is eleven-dimensional supergravity and which subsumes the five consistent superstring theories) and does the theory describe Nature?

Louise Dolan
University of North Carolina, Chapel Hill
Annamaria Sinkovics
Spinoza Institute
Linda Rose
San Antonio College

Question 8

What is the resolution of the black hole information paradox?

Tibra Ali
Department of Applied Mathematics and Theoretical Physics, Cambridge
Samir Mathur
Ohio State University

Question 9

What physics explains the enormous disparity between the gravitational scale and the typical mass scale of the elementary particles?

Matt Strassler
Institute for Advanced Study, Princeton

Question 10

Can we quantitatively understand quark and gluon confinement in Quantum Chromodynamics and the existence of a mass gap?

Igor Klebanov
Princeton University
Oyvind Tafjord
McGill University